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Blending customisation, context-awareness and adaptivity for personalised tangible interaction in cultural heritage

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ABSTRACT

Shaping personalisation in a scenario of tangible, embedded and embodied interaction for cultural heritage involves challenges that go well beyond the requirements of implementing content personalisation for portable mobile guides. Content is coupled with the physical experience of the objects, the space, and the facets of the context—being those personal or social—acquire a more prominent role. This paper presents a personalisation framework to support complex scenarios that combine the physical, the digital, and the social dimensions of a visit. It is based on our experience of collaborating with curators and museum experts to understand and shape personalisation in a way that is meaningful to them and to visitors alike, that is sustainable to implement, and effective in managing the complexity of context-awareness. The proposed approach features a decomposition of personalisation into multiple layers of complexity that involve a blend of customisation on the visitor's initiative or according to the visitor's profile, system context-awareness, and automatic adaptivity computed by the system based on the visitor's behaviour model. We use a number of case studies of implemented exhibitions where this approach was used to illustrate its many facets and how adaptive techniques can be effectively complemented with interaction design, rich narratives and visitors' choice to create deeply personal experiences. Overarching reflections spanning case studies and prototypes provide evidence of the viability of the proposed framework, and illustrate the final effect of the user experience.

1. Introduction

In a scenario of digital content delivery for the cultural heritage sector—either online or onsite—to adjust what is presented to the visitor is seen as essential to accommodate different visit motivations, expectations, and needs (Falk, 2009). Within the meSch project,[1] we addressed the challenges of supporting a personally meaningful, sensorily rich, and socially expanded visitor experience through tangible, embedded and embodied interaction (Petrelli et al., 2013). We envisage a cultural space filled with smart objects, each with their own stories embedded therein. Content will be revealed if and when conditions are right, e.g. visitors have picked up an object on display to inspect it, or a group has reached a certain location, or another smart object is close by. Visitors can continue their visit online—via a personalised interaction—to experience heritage in a novel way that combines the material and the digital. To create such a hybrid experience requires a personalisation infrastructure able to span the digital-physical divide. This in turn requires reconsidering how personalisation is done, which features should be applied and when—e.g. on-site or on-line—and, overall, how multiple contact points of the same institution can be orchestrated in a seamless extended and memorable experience.

'Personalisation' is a broad term that encompasses three types of system behaviour (Fink et al., 1998; Gellersen et al., 2002): *adaptability* (also called *customisation*, the term we use hereafter) offers users a number of options to set up the application/system the way they like it; *context-awareness* is the ability of the system to sense the current state of the environment and to respond accordingly; *adaptivity* implies the system maintains a dynamic model of the on-going interaction and dynamically changes its own behaviour to adapt to the changing situation. When applied to a scenario of tangible interaction, the concept of personalisation widens, as the interaction between the user and the system expands to include smart objects and networks of sensors, e.g. visitors hold smart objects or move in reactive spaces. The meaning of customisation, context-awareness and adaptivity must then be extended to include physical aspects. A visitor choosing a smart replica that holds one of many stories makes a choice of customisation—the visit is shaped by the replica that triggers specific content. A system that senses the presence of the visitor and their current visit preferences shows context-

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[1] meSch, Material Encounters with Digital Cultural Heritage was a EU funded project (2013–2017) www.mesch-project.eu.

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awareness that combines the physical and the digital. Finally, a system that offers tangible interaction shows an adaptive behaviour when it uses the dynamic model of the visit to craft a personalised souvenir tailored to what that specific visitor did. These few examples show how personalisation must be reinterpreted when the physical aspects become part of the experience.

This paper presents a multilayer framework to support personalisation across the physical and the digital. In collaboration with curators and museum experts, we set out to understand personalisation in a way that is meaningful to heritage and its visitors, that is sustainable for curators to implement, and effective in managing the complexity of hybrid experiences. To deliver such a complex personalisation service the overarching framework has: (i) to reuse the main functionalities in different contexts (e.g. onsite vs. online interaction); (ii) to facilitate porting applications to different sites, hardware devices, and heritage domains; and (iii) to implement personalisation for both content and interaction. It has to be an easy-to-use tool for curators who can, autonomously, create new stories and interpretations, as well as modify current exhibitions (Not and Petrelli, 2013). The paper is structured as follows. Section 2 gives an overview of the field of personalisation for cultural heritage and the new opportunities offered by tangible and embodied interaction. Interventions in museums and outdoor cultural heritage sites developed as part of the meSch project are illustrated in Section 3; they show a breath of multisensorial personalised experiences in both content and interaction. Section 4 reports a collaborative study with curators that questions the meaning of personalisation and the different features that must be taken into account. Section 5 discusses the personalisation framework and how complementary approaches allow for content creation to be controlled by curators while the delivery in context is controlled by the system. We also discuss how exhibition design choices that grant visitors some control on tailoring their experience (customisation) can be more effective than automatic logging and complex events processing (adaptivity). Section 6 concludes the paper with reflections on how different forms of customisation, context-awareness and adaptivity are supported by the proposed framework and their effect on the user experience.

2. Personalisation in cultural heritage: looking for new opportunities

The call for personalisation for cultural heritage has mostly been applied to content adaptation, i.e. to dynamically change the amount or type of information conveyed to the single visitor to fit what they like or know, and how they behave. However, an analysis of personalisation in cultural heritage over the past 25 years opens up possibilities and offers new challenges (Ardissono et al., 2012).

From mobiles (Stock et al., 2007b) to the most recent augmented reality (Damala et al., 2012), personalised interaction with digital information has been designed for individual use. But personal devices do not really immerse people in the space and the social context (vom Lehn et al., 2007; Martin, 2000): strong personalisation might end up isolating the visitor within a hyper-individualised experience, which is somehow unnatural in a museum context where it is most common to visit with family and friends (Lanir et al., 2013). In this way, personalisation misses out on the fundamental fact that the context affects the experience more than the visitor's cognitive and psychological status. Tangible, embedded and embodied interaction (Hornecker and Buur, 2006), in which digital content is revealed in synergy with the sensorial experience, has the potential to keep the exhibition at the centre of visitors' attention and strengthen the sense of "being here" (Dudley, 2009; Petrelli et al., 2013). In our research we investigate how tangible interaction combined with personalisation can support new forms of personal engagement where visitors are offered tailored experiences (both in content and interaction) "in place" (Ciolfi, 2015).

The visit is generally done in self-organised groups (family, group of friends, class, couple) or as a casual group (guided visits or in-place activities), but even when visiting alone, individuals move in a shared space and compete for the same exhibition resources. Personalisation of interaction according to proxemics and social context has recently gained attention, with some solutions taking advantage of projection facilities or situated public displays (Wecker et al., 2011; Stock et al., 2007a; Belinki et al., 2011) as well as screens and portable devices (Greenberg et al., 2011). Research that directly addresses the social dimension is still limited, e.g. group conversations around a context-aware table (Stock et al., 2011), sharing partially missing content to foster discussion on exhibition topics (Callaway et al., 2014), or sharing tablets among family members (Rennick-Egglestone et al., 2016). Exhibitions designed to engage visitors into shared interactions have proved very effective, even between strangers that just happened to be close to the installation at the same time (Heath et al., 2002; vom Lehn et al., 2007). These interactive pieces build upon the surprise triggered by the unexpected and the physical engagement that follows when trying to understand what happens. However, most of the time these interventions are individual artistic expressions not intended to bring the visitors closer to and engaged with the heritage and its stories. They are limited and understood as performances. Design can be used to amplify the physical engagement with the artefacts on display and foster social interactions (Wakkary and Hatala, 2006). Within this articulated research domain, we investigate how different personalisation techniques can be integrated to support a variety of experience patterns (e.g., very energetic and interactive vs. contemplative and emotional) that fit different social dynamics. The aim is to accommodate different motivations, emotional attitudes and expectations.

Finally, sustainability should be a founding principle for personalisation in cultural heritage (Not and Petrelli, 2013). For personalisation to become the norm it is essential that the system is conceived for: reusing the same functionalities in different contexts (e.g. onsite vs. online interaction); porting an application to different physical sites and to different heritage domains; supporting the preparation of content and the definition of adaptivity strategies; and enable easy maintenance.

3. Case studies

This section briefly describes the installations and prototypes based on tangible, embedded and embodied interaction used later in the paper to illustrate the multilayer personalisation approach. It intends to give a sense of the type of experiences enabled by the new Internet of Things (IoT) technologies as well as to show some of the design choices relevant to the discussion that follows. While these examples were developed to different degrees of refinement (some were just prototype, some one-point installation, some spanned across several stations, some moved from the physical exhibition to online content), they were all fully developed and were evaluated with participants in a series of studies. All the examples were created in co-design, that is to say museum professionals, computer scientists and designers collaborated in the concept ideation while later each expert focussed on their own specific area. When the concept was agreed, then work split: the content was always selected and curated by the museum while the designers refined the interaction and the computer scientists developed the hardware and the software (Petrelli et al., 2016a). The examples are given to support the discussion of the personalisation framework, readers interested in the single case studies could refer to published papers.

Narratives in the Trenches of WWI was an exploratory prototype designed to test, in the wild, the concept of the place itself telling the many stories of the people who lived there (Nagià Grom, Trentino, Italy).[2] It is composed of a set of Bluetooth-enabled loudspeakers encased in wooden lanterns positioned at points of interest in the trenches and fortified camp of WWI on the Italian Alps; the lanterns are paired with an interactive belt that hosts an NFC reader and a set of 4 cards (NFC

[2] https://www.youtube.com/watch?v=hLORDVpivhM (accessed 6.9.2017).

Fig. 1. Inspired by WWI soldiers' kit, the interactive belt was designed to be used while trekking in the Italian Alps to visit the trenches of WWI. The belt is worn by the visitor while the Bluetooth-augmented loudspeaker marks the point of interest. Visitors in the group negotiate what to listen next browsing through the thematic cards.

tagged). Each card is a perspective on the war: "Order of the day" is the commanders' voice and the more factual of the themes; "My dear wife" are personal accounts of the soldiers; "Women in the war" is the story, rarely told, of the civilians during war times; and "Poetry in the trench" is an evocative collection of poems written during the war. The interaction is triggered by presence: when a visitor wearing the belt enters the area of a loudspeaker, a loud sound attracts the visitor closer; when the visitor gets closer and is about 5 m away the loudspeaker plays the story of the theme (the card) currently inserted in the belt. The visitor can then change the card and listen to a different story or walk away and continue the visit. (Fig. 1) This prototype was evaluated with 9 volunteers who visited in small groups of 2 or 3; interaction logs were collected, the visit observed and the participants interviewed. They appreciated the automatic starting of the stories when they approached the points of interest, the quality of the stories and the variety. The logs showed every group took an individual visiting path and listened to more than one story in every place, but none listened to all content in every place. Finally, participants appreciated the possibility of choosing what to listen to and were observed discussing the content with their companions or commenting on the surroundings. The choices of topics seem idiosyncratic although the "Order of the day" was the most listened to. (Petrelli et al., 2016b; Marshall et al., 2016b).

Voices from the Past in Fort Pozzacchio complements a permanent collection of WWI artillery at the Museo della Guerra[3] (Rovereto, Italy) with the human aspect of the war and the stories of witnesses who had their life affected by the presence of the fort (Museo et al., 2016).[4] Besides the soldiers from the opposite armies who fought each other, the stories are those of the engineer who designed the fort, the army chaplain, the commanders, and the villagers before, during and after the war. Four thematic stations are positioned along the visiting route and feature several personal accounts (as an array of slots); each slot maps a personal story; the short stories (less than 3 min. each) and the many slots invite visitors to choose more than one content per station. At the entrance the visitor receives a smart object, a 'pebble', that conceals a NFC tag and that, when placed on a slot, activates multimedia content. When leaving, the visitor returns the pebble; its NFC is read by another slot that prints a personalised postcard with text automatically generated on the basis of the personal visiting path (Not et al., 2017) (Fig. 2).

The Hague and the Atlantic Wall was a temporary exhibition held at MUSEON[5] (The Hague, The Netherlands) on the effect the construction of the Nazi costal defence system had on the city of The Hague (Marshall et al., 2016a).[6] The same events were told by contrasting voices: the German soldier; the Dutch civilian; and the Officer who had to do the bidding of the occupiers against the population. Smart replicas of historical objects represented a voice and concealed an NFC. Ten display cases had an interactive ring (with NFC reader) on which visitors placed a replica, watched a video projected on the case and listened to the story via a hear piece. A final station with the same interactive ring printed a personalised postcard that gave access, via a unique code, to a personalised website where the visitors could contribute personal or family memories and explore those left by others. The exhibition was designed as a map of the city with every interactive station standing for a neighbourhood; similarly, the online interaction was shown as a map of The Hague with content from the exhibition shown with a meSch logo (grey or coloured depending if the content had been consumed during the visit or not); the visitors contribution was displayed as a pin on the map. At the entrance visitors chose one (or more) replicas as if they were following a character during the visit, they used it at every station and finally printed their personalised postcard (Fig. 3). The exhibition was open from April to November 2015; the logs show the replicas were used over 14.800 times but only 1557 (~10%) printed their souvenir and of those only 39 accessed the online system and added 62 pieces of content to the map (Petrelli et al., 2017).

The Loupe was an exploratory prototype tested in two different museums. Shaped as a magnifying glass, the Loupe conceals a mobile phone that uses Augmented Reality to trigger the display of content. In the version tested at the Allard Pierson Museum[7] (Amsterdam, The Netherlands), the "Children of Zeus" (Fig. 4), the Loupe was used to highlight engaging stories within a traditional display. It is implemented as a trail: the outline of an object is displayed on the Loupe, the visitor has then to find the object and overlap the outline onto the object itself. This triggers the display of specific content. The visitor could ask for more content by tilting the Loupe, this would display another snippet of text, or could move on by shaking the loupe to delete the current object and display the outline of the next one in the trail. The content was mostly text with the addition of an audio, two animations and three images. The text was broken into short snippets with a short description of the myth, a longer description, and an invitation to look at the object to answer a question before moving on. In the evaluation 22 participants were observed using the Loupe, individually or in pairs, completed a questionnaire, and some were then interviewed. Findings show visitors appreciated the novel interaction and were reading more than they would normally do, slowing down their pace to pay more attention to the objects on display (Van der Vaart and Damala, 2015).

In the implementation of the Loupe for the Hunt Museum[8] (Limerick, Ireland), two different trails were available for the visitor. Objects belonging to different trails had different visual markers, e.g. a shamrock for "The History of Ireland in 10 Objects" and an icon of the Hunt Museum building for "Architectural Perspectives" (Fig. 5). Here the visitor does not follow a trail by seeking the next exhibit on the screen, but chooses what to explore next by browsing the space to find the objects marked with their trail symbol: using the Loupe to focus at the symbol

[3] http://www.museodellaguerra.it/.
[4] https://www.youtube.com/watch?v=DReu2J7eWx4 (accessed 6.9.2017).
[5] http://www.museon.nl/.
[6] http://www.mesch-project.eu/smart-object-enhanced-museum-exhibition-atlantik-wall-at-the-museon/.
[7] http://www.allardpiersonmuseum.nl/.
[8] http://www.huntmuseum.com/.

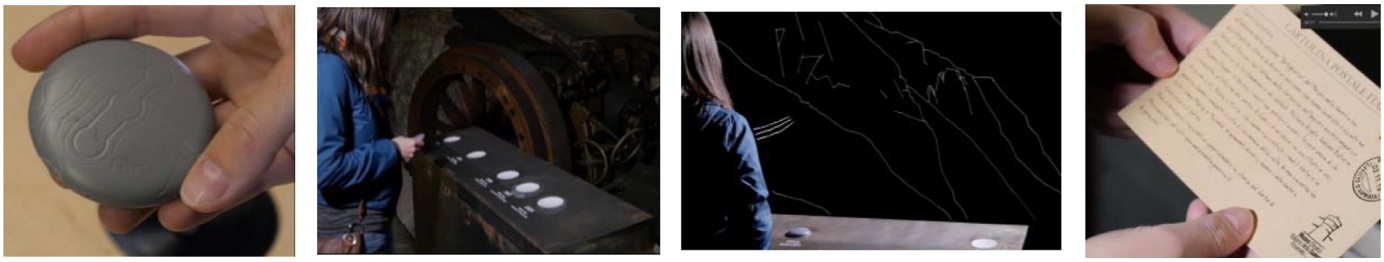

Fig. 2. Voices from the Past in Fort Pozzacchio is a permanent installation at the Museo Storico Italiano della Guerra. At the entrance the visitor receives a pebble used to activate content at different stations along the visit; when leaving the visitor returns the pebble and receives a personalised postcard with a summary of their visit. Each station has different content types: drawn animations on the story of the fort; evocative sounds and stories from the villagers; and video portraits of soldiers of the opposite army recounting the same battle.

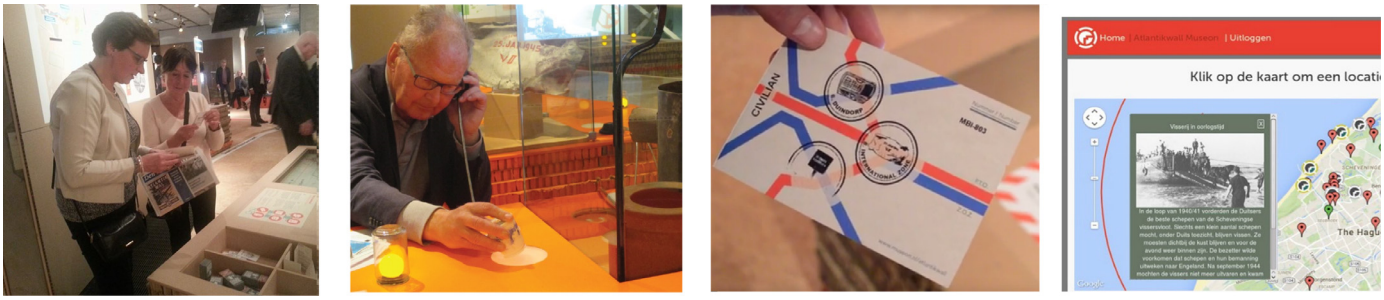

Fig. 3. The Atlantic Wall: visitors look at and choose the replicas to use during the visit (a); the interactive station reacts to a smart replica (b); the printing of the postcard (c) and the online interaction (d).

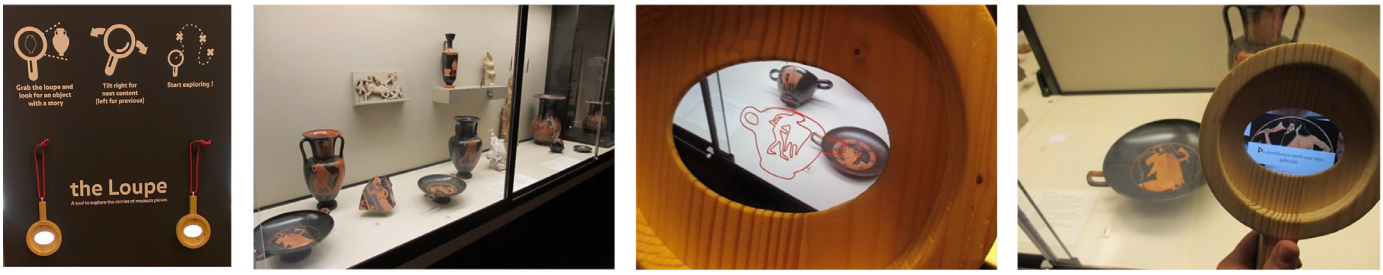

Fig. 4. The Loupe as used at the Allard Pierson Museum implements a trail. It shows the object to seek and allows to get information about exhibits by simply framing the object. Additional details are activated by tilting the Loupe. A shake of the Loupe displays the next object to seek.

Fig. 5. The Loupe was used at the Hunt Museum to get information for objects belonging to different thematic trails by matching different visual markers, e.g. a shamrock for a historical trail or the shape of a building for a trail on architecture.

triggers the content. As in the example before, tilting gets new content while shaking deletes it.

The Interactive Plinth (Fig. 6) was deployed at Museo della Guerra in January 2017 to encourage visitors to touch and learn about original objects. The station has two distinct areas: one area to showcase the objects and an active area. A message on the screen invites visitors to pick up one object and place it in the marked activity area that fits its profile. An audio track that describes the object, how it was made and what it was used for plays. The audio narration has a simple matching (white-on-black) graphical animation; captions on the screen highlight points in the audio. The visitor is invited to pick up and touch the object, observe it closely, possibly handing it to visit companions: these actions do not interrupt the presentation. When the audio is over, the visitor is offered with additional stories. If the object is held or left on the activity area the story starts automatically; if the object is placed back in its showcase position the presentation ends. When no more content is

Fig. 6. The Interactive Plinth was integrated in a permanent exhibition of WWI historical objects (left). Visitors are encouraged to touch the objects while object descriptions are being played (centre). Users can change the presentation language by means of buttons on the plinth top surface (right).

available, a message invites the visitor to explore a second object. Two buttons allow selecting the output language (Italian or English); pressing a button restarts the latest presentation in the newly selected language.

All the case studies presented offered several opportunities for personalisation both in content and interaction. In the following of the paper we illustrate how we came to the definition of the overarching personalisation framework that was used for the prototypes.

4. Shaping personalisation that is meaningful to professionals

Personalisation for cultural heritage has been a topic of research for many years (Ardissono et al., 2012), however no common understanding is shared across the community on which personalisation features (e.g. age, interest, visiting style, location, etc.) should be used and for which aim. In addition to this limited specification, tangible interaction opens up new opportunities to experience personalisation. To gain a better understanding of the most relevant features to consider and how these match the goals of cultural heritage professionals in providing meaningful experiences for their audiences we conducted two complementary studies. The outcome was used to define a personalisation framework suitable to model articulated tangible interaction scenarios. The first study is a meta-analysis of the literature that classifies the features used in different personalisation systems. The second is a user-centred qualitative study of what personalisation means to cultural heritage professionals. The results of the two complementary studies were then compared to produce an overarching framework and a set of guidelines for implementing personalisation for cultural heritage.

4.1. Personalisation features in the literature and their use

In order to determine which features have driven research so far and the computational approaches adopted, an extended survey of the existing literature was undertaken. The selection of work was broad and included both seminal works in the field of visitor studies rooted in extensive ethnographic investigations as well as technical papers describing implemented solutions evaluated with final users in onsite settings. Therefore our survey covered both museum scholarship as well as computer science research. Overall 41 features were classified according to the subject they refer to, such as the visitor or the environment, and to the static/dynamic nature of the information. Examples of the most significant features, grouped by information model, are shown in Table 1.

The features from the literature were then clustered by theme resulting in the following categories:

- *Stable visitor profile.* These are characteristics of the user that hardly change from one museum visit to the other, such as disability and socio-economic factors (e.g., age, education), psychological and cognitive factors (e.g., personality, general interests). If deemed important for the personalisation of the visit, features in the stable user profile should be acquired at the beginning of the visit or possibly imported from existing models of the user (e.g., through an import of information from user accounts on social media).
- *Visitor model related to the current visit.* These are characteristics that express the motivations, constraints, specific interests, specific knowledge, strategies to unfold the visit itinerary, and expectations the visitor has formed for this specific visit, and what they experience. These features may be (i) evolving during the visit, and therefore require constant monitoring and inference over logs (as the attention level, mood, acquired knowledge, etc.), or (ii) invariant throughout the visit, and therefore may be effectively captured either: at the beginning through a questionnaire; by design of choice-and-control activities; or through more complex modelling-by-observation in a "trial" phase.
- *Interaction or social context.* These are features that capture what happens during the visit in terms of physical and social interaction. They are separate from the "visitor model related to the current visit" category in order to capture the peculiarities of having tangible embedded and embodied interaction situated in a social context. This distinction is relevant in contrast to pure-digital or online interaction where this type of contextual features do not have a role.
- *Model of the environment.* These include characteristics of the physical environment that might have a significant impact on the experience to be designed, from macroscopic aspects (e.g. indoors vs. outdoors), to static aspects (e.g. physical layout of exhibition) and contingent aspects (e.g. weather conditions, crowd, noise).
- *Features of the content.* These are characteristic of the available content tokens (e.g. type of media, genre/register) or features of the narrative threads (e.g. long distributed story vs. multiple short stories).

The literature survey showed that implemented systems usually concentrate on the modelling and evaluation of one specific complex feature (e.g., visiting style) or on a subset of easy to model features (e.g., age, stereotypes, location), possibly leaving out other personalisation dimensions highly valued by curators but much more complex to identify and capture automatically (e.g., motivation for the visit). A strategy for prioritising the many possible features when deciding which personalisation to implement is still missing and, we believe, much needed.

4.2. The perspective of cultural heritage professionals

To have a fresh look at personalisation and to incorporate curators' views, we conducted a user-centred qualitative study aiming at understanding what personalisation means for cultural heritage professionals. Research from museum studies acknowledges that there is not such a thing as "the public" or "the visitors": the same person can visit many times, alone or with others, and each time have different motivations and therefore different needs (Falk, 2009).

During a co-design workshop that brought together curators, designers and computer scientists, we asked the 25 participants to contribute their thoughts on what must be changed in a visit to achieve personalisation. The group was composed by a core of researchers involved in meSch plus a number of invited guests with experience in heritage. It included: curators—10 participants from different museums; computer scientists and engineers—8 participants (only 2 with experience in per-

Table 1
Sample personalisation features discussed in the literature. The references cited in this table are Baltrunas et al., 2012; Bitgood, 2010, 2013; Brunelli et al., 2007; Dim and Kuflik, 2012; Falk, 2009, 2011; Falk and Dierkering, 2012; Ghiani et al., 2008; Goren-Bar et al., 2006; Hage et al., 2010; Kuflik and Dim, 2013; Kuflik and Rocchi, 2007; Not et al., 2007; Petrelli et al., 1999; Petrelli and Not, 2005; Pujol et al., 2012; Stock and Callaway, 2009; Tanenbaum et al., 2013; Tolmie et al., 2014; Vayanou et al., 2012.

Stable visitor profile	
— Age (Falk,2009; Petrelli et al., 1999)	— General interests, background knowledge (Falk and Dierkering, 2012)
— Personality (Goren-Bar, 2006)	
— Learning style (Falk and Dierkering, 2012)	— Disabilities (Ghiani et al., 2008)
Visitor model related to current visit	
— Motivations, interests, expectations (Falk, 2011; Dim and Kuflik, 2012; Vayanou et al., 2012)	— Visit history (Petrelli and Not, 2005)
	— Acquired knowledge and interest level (Kuflik and Rocchi, 2007)
— Previous visits (Petrelli et al., 1999)	— Fatigue (Bitgood, 2010)
— Visiting style (Kuflik and Dim, 2013)	— Visit constraints, e.g. available time (Petrelli et al., 1999)
— Attention level (Bitgood, 2013; Brunelli et al., 2007)	
Interaction context	
— Location, proximity (Hage et al., 2010)	– Interactions with objects (Tanenbaum et al., 2013)
Social context	
— Within-group and between-group social interaction (Falk, 2009; Kuflik and Dim, 2013; Tolmie et al., 2014)	
Model of the environment	
– Physical layout of exhibition (Hage et al., 2010)	— Weather conditions, crowding, noise (Baltrunas et al., 2012)
Features of the content	
– Type of media, genre/register (Not et al., 2007)	– Features of the stories, narrative threads (Stock and Callaway, 2009)
– Story plot (Pujol et al., 2012)	

Table 2
The 3 sets and 20 classes created out of the 176 entries suggested at the co-design workshop. In () the number of occurrences of the same or similar concept; in '' examples of the entries.

Content	
— Type (11) 'written text', 'spoken text'	— Perspective (9) 'level: easy-expert', 'fun vs. information seeking'
— Source (4) 'visitor's generated', 'curator's view'	
— Background (10) 'the real geographical origin of the artifact', 'story of use of the object: what is it? How was it used?'	— Narrative (11) 'multi path stories', 'conversation', 'stories as multiple connected points'
Context	
— Proximity (4) 'what is near?', 'proximity of the user/visitor to the object'	— Alone/group (6) 'lonely visitor', 'first date'
	— Environment (9) 'no power', 'no WiFi'
— Time/length (5) 'visitor just killing time', 'short visit'	— Devices/technology (11) 'enable digital shadows', 'own device, e.g. phone'
— Visit history (14) 'multiple visits – same museum', 'personal history'	— Engagement (6) 'touch', 'activating the senses: sound - smell'
Visitor	
— Take away (4) 'take-away bag', 'collect objects – virtual, physical'	— Mood/emotion (8) 'one's mood', 'mood selector of what I want'
— Leave (4) 'leave a message – comment!', 'enable feedback channel in context'	— Social interaction (11) 'who is around?', 'force social interaction'
— Unexpected (7) 'surprise me! Suggest me some content!', 'I believe in coincidence'	— Human body (5) 'age', 'disabled or special needs'
— Me (15) 'personal interest', 'how is the content related to my life?'	— Attention (4) 'current attention span', 'don't distract me too much from the content'

sonalisation); 7 designers (all with some experience in interaction design and experience in the cultural heritage domain). We briefed our participants and explained our aim as to collect the broadest set of personalisation features that could be used to personalise "content" in "context"; we used these two terms to broadly direct participants' thoughts towards two distinct clusters. We invited participants to write their features on post-it notes, read what others have contributed already and stick their post-it close to similar concepts under one of the two labels "content" or "context" or somewhere in between the two if they felt neither would do. Clusters of similar concepts were created in this organic way. A total of 176 post-its were collected. The content of the post-its was at different levels of granularity with some very precise features such as 'age' and other much more open such as 'no information but emotion'. A thematic analysis (Braun and Clarke, 2006) was used to systematically classify the post-its and create an affinity diagram: similar features were aggregated under a single label and a question was used to make the interpretation clearer; groups of labels were then aggregated under the same theme. In this way from a large number of small clusters a total of 20 classes (or themes) were created (8 entries were not classified as they were unique, such as 'hermeneutics' or 'intended educational goal'); the 20 classes were further aggregated in 3 larger sets that map the Content, the Context and the Visitor, as shown in Table 2.

When comparing the two sets of features, literature vs. user-generated, we can see that some occur in both sets such as 'age' or 'short time' or 'interest', but overall there are many more differences than similarities. We explain this by having in the group of 25 people only 2 with experience in personalisation systems; for the other 23 participants it was an exercise of imagination, on "what could it be?". The result is an unexpected and exciting range of challenges and opportunities. As it could be expected, the larger sets of entries refer to 'me' and the 'visit history', however features generally considered worth implementing in the personalisation literature such as 'learning style', 'visiting style' and 'personality' have not been mentioned at all in our sample. Intriguing is the large number of terms generated that is novel and has never been addressed by implemented personalisation. 'Unexpected' (7) and 'mood' (8) clearly indicate an interest in interactions that are different from what is generally provided by technology designed for cultural heritage, that is to say they point toward emotion rather than information. A similar call for affective engagement is found in other entries such as 'how is this content related to my life' classified as 'me'. From an implementation point of view this affective dimension is a serious challenge that, we believe, must be addressed by other means than computation; in meSch we used design. In other words, we designed experiences that enabled visitors to choose among a wide range of content that best matched their moods, including poetry, songs and music, jokes, personal accounts, news and propaganda, historical images and videos. We then provided visitors with physical objects to be used to select their preferred content and shape their visit in the way that best suites them. To use the terminology of personalisation, we used customisation as a way to match emotional needs.

The user-generated features also show the importance given to the content and the direct engagement of visitors with objects. For the content, the heritage is seen as a complex canvas on which multiple narrative threads can be weaved over the physical space. Our participants acknowledged that many layers of knowledge exist (the 'background') that can feed different perspectives. The direct engagement with interactive objects and spaces is, instead, a new and different take on personalisation for cultural heritage seen as a challenge (Ardissono et al., 2012).

The three sets above Content, Context and Visitor, point at three major ingredients that shape the visit experience. We use these as the building blocks of a personalisation framework that envisages: the curator-supervised preparation of the content and of the overall visitor experience; the system-controlled adaptivity of the content to the context; and forms of visitors' driven customisation.

4.3. Principles for personalisation in cultural heritage

The co-design study carried out with curators and museum experts showed a very different set of features than those used in implemented systems. Taken together the two complementary sets provide a comprehensive range that allows us to rethink personalisation as a combination of customisation, context-awareness and adaptivity actions performed by different actors at different stages, i.e. from the design of the interactive intervention, to the preparation of the content and the final delivery to visitors. Table 3 shows how the features have been classified respect to the type of personalisation performed and the actor responsible for it; different shades of grey aggregate features that impact different stages of personalisation preparation, coding and execution.

In Table 3 some entries summarise features that occur under different labels in the literature (Table 1) and in different keywords mentioned by the curators (Table 2). For example "interest in topics and narrative threads" in Table 3 aggregates features such as "general interests, background knowledge" from the literature (Falk and Dierkering, 2012) as well as "me", "personal interest" and "how is content related to my life?" identified by curators. What curators call "attention", "take away", "social interaction", "mood/emotion" and "unexpected" is grouped in Table 3 under "type of visit", i.e. different types of experiences the visitors may wish to have. What in the literature of implemented systems is referred to as "visiting style" (Kuflik and Dim, 2013) and "acquired knowledge and interest level" (Kuflik and Rocchi, 2007) is in Table 3 the general category of features that require a modelling of "history of individual interaction with objects/places and content delivery".

Although this is an attempt to be as exhaustive as possible in classifying personalisation features, the features do not all have to be supported by every system. Instead each cultural heritage setting has to be considered in its own right: the most suitable combination of customisation, context-awareness and adaptivity depends on design choices made on the bases of the curators' objectives and the specific visiting audience. For example, many science museums are visited regularly by families with pre-school children while this type of visitors is rare in war museums that instead welcome many school visits. Therefore each intervention should choose the most appropriate combination of features and how to implement them. Below we offer four principles that should be considered when deciding on a specific design; they derive from our understanding of both the literature and the needs of the professionals.

Choose features that shape different experiences. Not all the features for personalisation produce the same benefit, or are easily portable across different settings. Features that are simple to acquire and to model (like age) can in principle be taken as the basis to infer automatically what might be interesting for that visitor, but the risk is that the corresponding stereotypes oversimplify the current visitor needs and preferences (Falk and Dierkering, 2012). For example, the stereotype that a child (young age) has limited knowledge (respect to an older person) may be very wrong as some children can be so passionate about a subject (e.g. dinosaurs, ancient Rome) to become domain experts. Therefore, to rely on easy features may be counterproductive. By contrast more complex features such as visitor motivations or personal interests for current visit are highly valued by curators and are more effective in representing the visitor's expectations, behaviour, and visiting style. Indeed such complex features can help model various aspects of personalisation simultaneously, e.g. personal interest implies spending more time and going more in depth.

Design to model complex features. Techniques at different levels of computational complexity can be used to model the features that relate to visitors, their evolving experience, the social context, and the environment. Possible personalisation approaches include: the sophisticated processing of logs and events for deriving inferences on what is going on (e.g., *guessing* the current focus of attention or the interest level); the request for the visitors' collaboration and input (e.g., *asking* for preferred thematic threads); and the import of known data from external services (e.g., *knowing* the weather forecast). What computa-

Table 3
Classification of features on the basis of the type of personalisation they support (customisation, context-awareness, adaptivity) and of what controls them (context, curator/designer, system, visitors).

	Features depending on Context	Decided by Curator and Interaction Designer	Modelled by System	Chosen by Visitor
Customisation preparation	– Onsite/online visit – Type of space (in-doors/outdoors) – Technical constraints (e.g. no power sockets, no WiFi)	*Content selection stage* – Heritage topic / domain – Content media type – Genre of text – Range of available thematic threads – Supported profiles – Types of social group *Story preparation* – Structure of narrative (e.g. storytelling vs. Q&A) *Interaction preparation* – Structure of interaction (e.g. guided visit vs. free exploration vs. treasure hunt)		
Context-awareness		– Input and output interaction abilities of the augmented objects	*Experience instantiation* – User location – Proximity to objects – Proximity to other users – Current state of objects	
Adaptivity			– History of individual interaction with objects/ places and content delivery – History of collaborative interactions	
Customisation choices				*Experience control* – Visit motivation and expectations – Interest in topics and narrative threads – Expected duration of visit – Type of visit (emotional vs. social vs. informative vs. fun)

tional approach is selected for which personalisation feature depends on a sustainable trade-off between: the reliability of the modelling, the time readiness of information, the portability of the approach to different domains and hardware settings, and the computational cost. The research we conducted in meSch showed that visitors who have a role in shaping their experience feel a strong personal engagement. Thus, instead of asking visitors to fill in questionnaires and match the answers to a profile that delivers content to a passive audience, the visitors are offered the active role of choosing and controlling some aspects of the visit while the system monitors these actions to fine tune the experience. To be requested to take an active role empowers the visitors and evokes a sense of appropriation; this in itself is an advantage over forms of transparent personalisation based on live-data of the visit, where the visitor is not requested to engage directly as the system dynamically adapts to visitors' behaviour. An active role makes the visit "my visit" and therefore reinforces the personalisation effort carried out by the system in the background.

Keep curators in control of the stories and the experience. Personalisation as intended by computer scientists often implies curators have a very limited role to play in the creation of the visitors' experience, for example when the personalisation system uses a knowledge representation and rules (Ardissono et al., 2012; Callaway et al., 2005). However, what content is delivered to visitors and how is part of the museum mission, and curators feel certain aspects of personalisation must be under their control, such as the provenance and the type of content used, the interpretations and perspectives available. Curators then

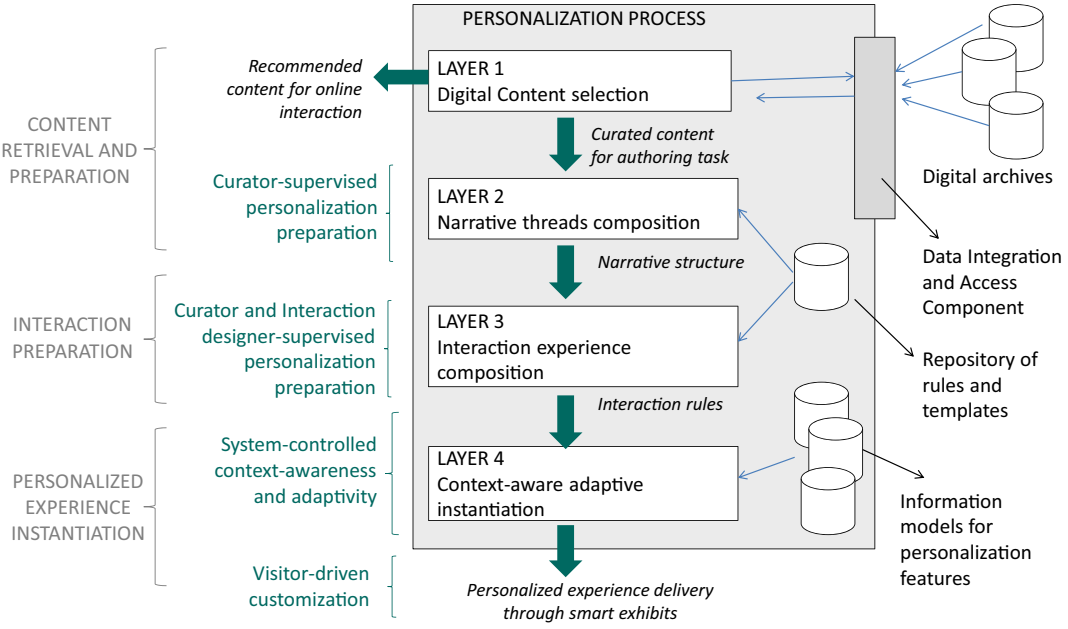

Fig. 7. Multilayer Personalisation Framework supporting customisation, context awareness and adaptivity.

should be those in charge of the stories told by the system; they should have tools for searching and uploading content tokens (i.e., portions of text, audio snippets, images); they should be able to create alternative perspectives and thematic threads, and different levels of detail. Support should be given to match the many variables that influence the final delivery of the intended experience, specifically the variability in content with the desired interactions (Risseeuw et al., 2016). In this way the curators will have the confidence that the system will deliver what they want it to.

Keep the instantiation in context as a separate phase. When the museum curates the narratives and the visitor has an active role, the personalisation system then can exploit this information on the delivery of content (curated by the museum) in the specific context of the visit (accommodating visitors' choices). In other words, content and context are kept distinct although tightly connected. By keeping the rules for runtime context-aware instantiation of the experience separated from the description of narratives, it is possible to decouple the curator authoring task from the physical architecture, facilitating the reuse of exhibition templates with different hardware setups. Thus, the heritage professionals will focus on the personalisation they are already familiar with (different stories for different visitors) and on the exhibit objects they want visitors to interact with, and leave the system to deal with the sensing and modelling of a dynamic context that determine how the story is delivered. This separation is key in the personalisation framework presented below.

5. A multilayer framework for customisation, context awareness and adaptivity

The study above underpins our approach to experience creation and personalisation that is based on a clear separation of content from interaction, and aims at facilitating the preparation and the reuse of (i) the narrative threads that can be adapted to different visitors and types of experience and (ii) the interaction strategies that describe how content should be released in a specific context.

To assist the creation of interactive experiences that feature different forms of personalisation, a multilayer framework (Fig. 7) was defined and implemented to separate the retrieval and preparation of the content (Layers 1 and 2), the preparation of the expected type of visitors' interaction (Layer 3) and the rules for context-aware adaptive experience instantiation (Layer 4) (Not and Petrelli, 2013). These layers map the different clusters of personalisation features identified in Table 3.

Layer 1 enables the selection and curation of the content items used to compose the experience. It is at this stage that cultural heritage professionals access data archives of their institutions or other open access resources, such as Europeana, to look for existing suitable media items. During this phase, curators may benefit from contextual search that uses information about the institution or the task in hand (e.g. the subject-matter domain, frequently used search strings, content already selected) to suggest a filtered list of results potentially more relevant for the current authoring task (Hashemi et al., 2016). Personalisation here maps system-led customisation as the suggestion of new content derives from static settings such as the type of museums (archaeology vs. science) or its settings (indoor vs. outdoor).

Layer 2 extends the approach proposed in Petrelli and Not (2005) of composing content in a narrative network where nodes are controlled by if-then-else rules with conditions over customisation features. The outcome of this stage is a set of content data annotated with customisation choices related to: the features of the visitor in the static user profile (e.g., spoken language) or modelled by design (e.g. interest in topics and thematic threads); the structure of the story (e.g. whether parts of the story are to be delivered in different steps or the story is narrated all at once); the history of content delivery (e.g., whether a certain content has already been delivered or not). Templates can be used to speed up the editing: curators upload new content on a given node via a simple graphical user interface (Risseeuw et al., 2016). Templates can also be modified to create different experiences with minimal effort, for example "The Hague and the Atlantic Wall" scales up "Narratives in the Trenches of WWI" from 7 to 11 points of interest and reduces the number of alternative stories from 4 to 3.

While Layers 1 and 2 deal with the content and the narratives, Layer 3 moves the focus to the context of the visit and introduces additional personalisation options that shape the interaction experience with the augmented objects and the space. The outcome is a richer set of annotations related to: the features of the interaction context (e.g. the visitor's position or his actions over the objects); the features of the social context (e.g. proximity of visitors belonging to the same group); the features of the environment (e.g., the noise level). An interaction script describes how the annotated narrative network should be traversed by means of context-awareness and adaptivity rules based on those fea-

tures (e.g. “If the visitor is at about 20 m from a point of interest, then play a content item associated to that point of interest and annotated as content for attracting visitors” is one of the rules for “Narratives in the Trenches of WWI”, Fig. 1). More complex rules can be written to map the content annotation in Layer 2 with the input/output interaction capabilities and the actual interaction design. Visual paradigms could be adopted at this stage to support non-technical people in writing rules, as in the approaches recently suggested by Ghiani et al. (2017) and Desolda et al. (2017). Within the meSch project, research was conducted on visual aids for composing the if-then-else rules as an extension of the Google Blockly library (Stratton et al., 2017). However, if cultural heritage professionals would feel confident enough to edit the rules by themselves is not certain. Indeed our co-design work points in the opposite direction: while they are comfortable with preparing content, curators prefer more technically skilled interaction designers to take care of the rule editing. The key issue seems to be the ability to generate the logic of the scripts. In a series of events targeted to heritage professionals, the meSch interface based on file tagging was used with ease by participants to extend existing interactions to, for example, support a new output language or to add new smart objects. In our view this demonstrates confidence in modifying an existing and proved interaction; creating interactive behaviours from scratch is instead a step too far that calls for a collaboration between heritage professionals and interaction designers to manage the activities in Layer 3.

Layer 4 implements the intelligence for contextual instantiation and execution of the adaptive networks and interaction scripts prepared at the previous stages, including low-level mediation strategies for playback. This service supports the monitoring of the interaction events during the onsite/online visit and performs the execution of the adaptive rules that instantiate the actual experience delivered to the visitors. This includes resolving conflicts when alternative system behaviours are possible. An example is “Narratives in the Trenches of WWI” (Fig. 1) where the content delivered depends on the precise position of the visitors (close/far from a point of interest) and their specific choice of topic.

Overall this framework brings together in a coherent way different personalisation features and enables bespoke installations to use the combination of customisation, context-awareness and adaptivity that best fits the specific heritage. By separating the content from the context this multilayer framework enables reuse: the same structured content (defined at Layers 1 and 2) can be loaded onto different smart exhibits so the content will be activated in different context, i.e. different interactions (specified at Layers 3 and 4). For example, the same content describing the trenches of WWI was used both with an augmented belt with thematic cards (Fig. 1) as well as with a digitally augmented book whose thematic pages can be selected by positioning a magnetic bookmark (Petrelli et al., 2016b). Similarly, the same smart exhibit can hold different structured content so that new presentations will be offered for the same interaction: for example, the digitally augmented book tested at the WWI trenches, was originally used with different content to help visitors discover the Sheffield Hallam General Cemetery (Ciolfi et al., 2013). This leads to sustainability as the initial investment for the smart exhibits covers a number of different exhibitions each one with a different content. Moreover, the same exhibition could travel to different institutions that will change the content to suite their visitors.

6. Evaluation of the multilayer personalisation

The proposed framework splits personalisation into multiple layers of complexity that involve a blend of (i) customisation on visitor initiative or according to the visitor profile, (ii) system context-awareness, and (iii) automatic adaptivity computed by the system based on visitor behaviour models. This framework and the design principles outlined in Section 4 have been used to develop the installations described in Section 3 demonstrating the framework is optimal to support onsite experiences where:

- curators maintain their pivotal role in conceiving high quality, multilayer narratives that engage visitors at both cognitive and emotional levels;
- visitors appreciate they have a role in deciding what to experience and at which level of depth; they are aware they are building their own path and feel more involved;
- the system is able to introduce elements of surprise and to keep the interaction coherent with visitors’ movements and gestures throughout the whole visit;
- there is the opportunity to adapt what is presented to visitors to take into account what was already experienced for a more personal message, to reinforce information that might have not been assimilated, to provide additional levels of information to visitors who are more deeply engaged with the exhibit objects.

The points above distil our understanding from a number of studies and evaluations. Below we go more in depth and discuss the most significant findings related to personalisation that emerged from 6 evaluation studies that involved 279 visitors using the 5 prototypes described in Section 3, all based on the multilayer personalisation framework.

We believe that a good personalisation is invisible, i.e. it is not perceived as a “special effect” or something exceptional, but smoothly accommodates visitors’ expectations and needs. The aim of personalisation is to facilitate the dialogue between visitors and complex forms of heritage comprised of many stories and many options. But then, how do we evaluate something that, if everything goes well, the visitors is not aware of? How can we measure the effectiveness of the synergistic work of the curator and the system to adjust the content and the interaction for the visitors? In meSch we evaluated the outcome of personalised interactions within a naturalistic setting: instead of a deductive approach based on rigid user evaluations (e.g. assigning tasks to participants and monitoring their execution) we used an inductive approach and looked at the individual enjoyment of the visit exhibition/interaction. A combination of qualitative and quantitative methods was used to identify critical points without disrupting the visit. Below we bring together results from several evaluation studies and organise them around emerging themes across the different installations.

6.1. Personal engagement through content

First and foremost, high quality content is pivotal to deeply engage visitors at the cognitive and emotional level and involve them personally. Even though deep engagement provoked by content cannot be directly classified as one of the forms of personalisation in its traditional definition (i.e. customisation, context-awareness, adaptivity), it was explicitly mentioned by cultural heritage professionals during their workshop. The category “me” (i.e. the personal engagement of the visitor) is one of the most frequent in reply to the question “what must be changed in a visit to achieve personalisation?” (see Table 2). For curators, content design should aim at creating an evocative experience by intertwining the sense of being in place, the narratives and the bodily interaction. Therefore, the content creation phase (Layers 1 and 2 of the framework) should encompass different types of emotions curators may want to evoke, a clear connection with what visitors will see (objects, places), and whether the content can provoke comments among group members.

In meSch we have experimented with different media (audio only, video, still images and slideshows, graphical animations, displayed text, textual summaries, graphical summaries), languages, genre (poems, military journals, personal diaries, object descriptions, historical newspapers, satire, songs, descriptions of historical events, anecdotes, play writing style, question answering as well as more traditional curated text), effects (surrounding sounds, evocative sounds, music, theatrical recitation, e.g. formal commanding voice vs. intimate and reflective voice) and we have studied their impact in shaping immersive and person-

ally involving experiences (Marshall et al., 2016b; Museo et al., 2016; Petrelli et al., 2016a, 2016b).

The importance of content quality was in focus in the evaluation of two case studies, "Narratives in the Trenches" (Fig. 1) and "Voices from the Past" (Fig. 2). The stories were drawn from the museum archives, specifically from diaries or memories written during wartime or from oral history collected by the museum over time. The evocative effect of personal narrations was amplified by the theatrical rendering of actors reciting or performing and complemented by music and sounds. In both cases the play occurred in very evocative surroundings, in a beautiful landscape (the trenches) or in caverns (the Artillery gallery).

Participants much appreciated the high-quality historic research of curators, the selection of the contents from original documents, the evocative acting of the narrated stories, which provide credibility to the multimedia content, and a delivery in place that did not make use of technological devices. Most of them felt engaged by the narrated stories (in "Voices from the Past" of the 143 participants who filled in the questionnaire 30% agreed and 58% strongly agreed). A specific interest in the personal stories clearly emerged during the interviews: *"I loved it because even for people like me, who don't know about weapons, hearing the civilians' stories through multimedia is an almost emotional experience. It makes you see things with different eyes. You don't just see a cannon, you find out how it affected the lives of many people."* Different participants favoured different content and felt free to discover and hear what they wanted, while at the same time felt motivated to listen to most or all the available stories (25% agreed and 65% strongly agreed). This confirms that the design of a content structure with multiple stories and depth combined with an engaging interaction mode empowers visitors to explore and discover what they like most and fosters appropriation. Offering options for the visitors to choose from is, in our view, a better strategy than for the system to second-guess what the visitor may want. We also see benefit in proposing variety including what one would not generally pick, an invitation to experience something different: "*I am not one for poems … but it is different, a poem in here.*" (from the interviews of the "Narratives in the Trenches" case, Fig. 1). This last point is radically different from what personalisation systems generally do that is to propose more of what is known or liked. For a personalisation system to diverge from the known is possible, but there is the risk of irritating the visitor: to offer alternatives that a visitor can willingly pick allows starting a new exploration path in a self-directed and natural way.

A different strategy to engage visitors with content was adopted in the implementation of the Loupe at the Allard Pierson Museum (Fig. 4). Here text provided by the curators was elaborated on by a playwright to create a narrative with "cliff-hangers" that invited the audience to continue the physical-digital exploration. For example, the story snippet shown on the Loupe "Heracles is the son of the mortal Alcmene and king of the gods Zeus. What is he hunting for?" invites the visitor to look at a vase and introduces background information about Heracles and his famous 12 labours before diving into another exploration of the object with two consecutive snippets: "First, he had to kill the Nemean lion. The skin of this animal could not be penetrated by weapons. Heracles strangled the lion and tied its skin around his shoulders." then "How is Heracles using the lion skin to protect himself on this drinking cup?". The evaluation showed visitors engaged with the exhibition switching their attention from the Loupe to the object and claiming they were reading more than they would do in a normal visit.

6.2. System customisation over visitor initiative

The study on personalisation as seen by the cultural heritage professionals (discussed in 4.2) points toward features such as "mood/emotion" or "unexpected" that are difficult to anticipate and extremely challenging (or impossible) to model. Instead of attempting to give the system more intelligence by second guessing visitor's temporary disposition and then offer a single option chosen by the system, in meSch we have taken the decision to exploit the new opportunities opened up by tangible interaction and offer visitors a range of different experiences they can choose from, together with the opportunity to change their mind or to select more options at the same time. For this to be possible, the framework supports the preparation of multiple content options (Layers 1 and 2), the definition of the interaction behaviour script (Layer 3) and the combination of visitors' choice with autonomous decisions of the system (Layer 4), this last possibly focussed for example on the movement in the exhibition space or on visit history. We call this approach *personalisation by design* as it requires a substantial design phase of the intended experience, the careful preparation of content and of different interaction options that are offered to visitors in an intuitive and tangible way. The case studies in Section 3 show several examples: the cards, the smart replicas, the pebble, and the loupe. This approach was used and evaluated in the case studies to measure visitors' acceptance and willingness to customise their visit and the impact this had on their experience.

6.2.1. Theme selection

A well-known way to collect preferences for the initial system setting is to implement a questionnaire-filling first step followed by stereotype matching (Roussou et al., 2013; Petrelli and Not, 2005). However, when visitors can easily select the places, themes and contents they feel are most interesting, the (boring) questionnaire filling step can be skipped. We designed experiences where visitors get straight into the visit and make their choices in context: the system benefits from this accurate bootstrap as it can be used for a more precise personalisation in the following interaction. Tangible interaction also offers intuitive means for small groups to negotiate choices on preferred themes that would otherwise be difficult for the system to automatically compute.

In Summer 2014, for the immersive auditory experience "Narratives in the Trenches" (Fig. 1), we evaluated the visitors' appreciation for an autonomous selection of themes and their willingness to explore all the available content via tangible means (Petrelli et al., 2016b). Visitors were free to choose their own visiting path, stop at points of interest and choose what to listen to by selecting a card; on this basis the system then personalised the play of the audio files taking into account the position (both point of interest and distance), the current thematic choice and if a narrative has been played last. The theme selection was via four illustrated NFC-augmented cards and visitors were observed discussing themes and what to listen next (Fig. 8).

The visitor study conducted with 9 participants showed that variety was the norm in the sequence of visit (Marshall et al., 2016b). Visitors demonstrated a clear appreciation for self-customisation, i.e. for the possibility of freely choosing which themes to explore, in which order, and how much content to experience at each hotspot. Empowering visitors with content choices based on a material interaction also fostered collaboration within small visiting groups and the sharing of the experience (Fig. 8). These results were confirmed by the more extensive evaluation study carried out for the Atlantic Wall exhibition (Marshall et al., 2016a); at the start visitors choose a perspective to follow by taking a smart replica that represents it and placing it on active hotspots (Fig. 3). The evaluation showed that visitors selected the smart replica on the basis of the perspective they wanted to listen to; sometime they carried two smart replicas when they were interested in contrasting stories, most frequently the Dutch civilian and the German soldier. When visiting in groups they were often choosing different perspectives (i.e. they carried different objects) and used the fact that they listened to different stories as a way to stimulate discussion and share their experience

The "pebble" in the "Voices from the Past" (Fig. 2) used to select a specific story at each station had the same effect: "*The object itself is pleasant to hold. It's nice to know that you can choose what to listen to. … It's as if you can take the experience along with you.*" and "*The Pebble gives you the chance to create your own route at your own pace.*" To hold a tangible object was key to make visitors aware of their thematic choice and that they are building a personal visit. Making choices had a much

Fig. 8. A couple negotiating and selecting the theme for audio narration.

stronger effect than we expected in terms of emotional involvement and engagement with the exhibition: "*Holding [the pebble] gives you the sensation of "entering" the world that you are hearing about and makes you feel more involved.*" and (from Atlantic Wall) "*I chose [the sugar box] that is a lot of Dutch civilians talking about their experience during the war and it was great because you hear all this personal stories and you get far more than going around and reading it.*" Although we did not probe for a different, passive setting in which the visitor receives content chosen for by the system, the wording used seems to tightly bond the emotional experience to the choice of the object and the holding of it during the visit.

The Loupe tested at the Hunt Museum (Fig. 5) offers another example of how thematic choices can be offered. Although the organisation of the content network into multiple narrative threads is the same as in the previous examples, here visitors look for and select alternative visual markers to be framed with the Loupe to activate the corresponding content. The content structure is the same (Layers 1 and 2) but the interaction is different (Layers 3 and 4), thus demonstrating how the framework flexibly supports the combination and reuse of content and interaction strategies to create a rich variety of experiences.

6.2.2. Profile specification

If multilingual material is available, the preferred output language is a choice for visitors done generally at the entrance as part of an initial profiling. Initial profiling can be facilitated by smart objects: a brooch augmented with a Bluetooth Low Energy device was used in a lab demonstration to store language (Italian vs. English) and content type (for adult vs. child) to automatically adapt the content when the visitor reaches a display case. At the entrance visitors received a brooch for their profile (a unique combination of adult vs. child and English vs. Italian) and a set of augmented cards to be used at each station: the interactive display case sensed the approaching visitor and used the information in the brooch to select the correct content when the augmented card was placed on the interactive case. A similar approach was used in "Voices from the Past", pebbles in different colours were for different languages, and in "the Atlantic Wall" where different objects combined language and perspective. These are examples of combining customisation, context-awareness and adaptivity to different degrees.

Embedding profiles within objects that the visitors select at the beginning of the visit opens up new possibilities. For example one can imagine different visiting experiences to be designed to map Falk's motivations for the visit (Falk, 2009, 2011) and offered as different objects; on this visitor's choice the dynamic personalisation is then rooted.

6.2.3. Request for additional information

To automatically adapt the amount of information delivered is a form of personalisation that has often been investigated in the literature (Ardissono et al., 2012). However, it may be difficult for the system to precisely determine the visitor interests and to adjust its verbosity accordingly. If tangible interaction is properly designed, we can replace the system's automatic guessing (that would be implemented in Layer 4 of the framework) with visitors' explicit actions, thus empowering people with more control over the presentations.

When using the Loupe prototype, evaluated with visitors both at the Allard Pierson Museum in Amsterdam (22 participants, Damala et al., 2016a) and at the Hunt Museum in Limerick (17 participants), visitors have to explicitly request additional information about an object on display by tilting the Loupe. The results of the user study conducted at the Allard Pierson Museum confirmed the positive attitude of visitors to seek additional information according to their personal interest and level of expertise (Fig. 4). Visitors mentioned being driven by curiosity to read more after each short section of text, a feeling induced by the creative writing style of the narrative that alternated reading text on the Loupe with observing the object on display in response to provocative questions. Interviews confirmed that different visitors experienced different quantities of information, with nine out of fifteen visitors who had read all the text (Damala et al., 2016a). These findings were confirmed by the user study conducted at the Hunt Museum where most visitors wanted more, rather than less, information (Fig. 5). People who decided to use the Loupe at the beginning of the visit were interested in learning more and were actively using the Loupe throughout the visit as a tool to help them receive more information, though the tilting gestures seemed to require some time to get used to.

The two studies showed that when visitors are empowered with tools with an intuitive design and physical affordance, they seek more information. However, asking for more may not be limited to "more of the same". Experiences like "Narratives in the Trenches" and "Voices from the Past" invite visitors to deepen their interest by listening to contrasting voices and the evaluations showed that they do. Indeed all the participants in both studies listened at least to two pieces of content at every point of interest or interactive station, sometimes they listened to all the content available showing an interesting form of self-regulation depending on what content was provided. What is common across these

experiences is that the content is split in separate small chunks. “The Atlantic Wall”, instead, had longer pieces of content with a video lasting for 14 min; the logs showed only a few visitors listened to the content in full further supporting the conclusion that how much content is delivered should be left to the visitor to decide.

6.3. System context-awareness

Some forms of personalisation depend on the ability of the system to monitor the state of the environment, of the interactive objects and the actions of the user. Whether these forms of personalisation are used or not depends on the design of the interaction rules in Layer 3 of the framework and on the sensing mechanisms implemented at the lower level in Layer 4.

6.3.1. Awareness of presence and proximity

The possibility of personalising the visitor experience according to users’ location and proximity to hotspots has a long tradition in the field of personalisation for cultural heritage (Ardissono et al., 2012). “Narratives in the Trenches” (Fig. 1), is the prototype that better represents our effort in meSch. The scenario can be experienced by simply walking around: the system tracks the visitors’ movements and reacts accordingly playing the right piece (of music or story) relevant for this place and the choices made by this visitor.

The analysis of the interviews, combined with the observations, confirmed that key to the appreciation of the experience was the seamless interaction. The attraction sounds had the double effect of rising surprise and increase awareness: “[the attraction sound] *is like the place is welcoming you*”. When hearing the sound coming from a point of interest nearby, visitors were observed changing direction and move towards the sound source so detouring from their path to reach the location. The automatic start of the narrative then induced people to stop and listen, while visually exploring the environment: “*the automatic start is brilliant*”; “*the music first when you are still far: really beautiful. Then you approach it and the story starts. It’s like it acknowledges you have arrived*”. There was also a theatrical effect in some of the locations such as inside the caverns where the sound lanterns were not visible, and audio resonated all around (Marshall et al., 2016b).

It is clear that, although technically not complicated to implement, location awareness can significantly improve the visitor experience when it is coupled with a careful interaction design sensible to the context and the environment of use.

6.3.2. Awareness of visitor actions and state of objects

Similarly to location-awareness, the awareness of what actions are performed by visitors and of the state of objects (e.g. position, internal state, proximity to other objects, time spent in place, etc.) can be used by the system to decide how to react coherently to users’ behaviour. For example in the “Atlantic Wall” exhibition, by monitoring the placement and removal of smart replicas onto the active areas of interactive cases (Fig. 3), the system controlled the presentations start and stop and cumulated a model of which stations the visitors spent the most time at. This monitoring was meaningful as the videos were quite long, up to 14 min; if the visitor decided to move on and took the replica before the video was over, the play stopped. Each time a replica is used an event is added to a log; this enables the system to know where this replica has been used (the sequence of the stations) and for how long (if it was removed before the video was over) enabling the personalisation (adaptivity) of the souvenir postcard, discussed below.

Context-awareness might also involve complex reasoning, as in the case of the new interactive plinth installed at Museo della Guerra (Fig. 6). Here the interaction is not regulated by a simple play/stop schema based on the presence of the object, but depends on a sequence of actions made by the visitors—who are encouraged to touch, lift and put down original exhibit objects while the presentations are playing—and on the different positions that objects can take—at the centre of the plinth, in the hands of visitors, or in their showcase position. The implementation of this form of context-awareness required the definition of a finite state automaton that models the internal state of the system (i.e. idle, presentation playing, waiting for specific users’ actions). The visitors’ interaction behaviour was modelled to decide when to automatically start additional information: further stories about an object are presented to those visitors who have completed the physical exploration of the object and heard its description until the end and still have it in their hands. A heuristic evaluation noted that the first video felt long and the automatic start of the second layer of information created a very long presentation. In this version the visitor was not aware that the content was actually composed by two parts and the combined listening could trigger a sense of information overload. In the new version, the system’s decision to present additional information is feedback to visitors with an explicit message displayed on the screen that explains what would happen next (an additional story would start if the object is held) and what can alternatively be done (put the object back in its showcase position and choose a different object). Within the ongoing evaluation of the interactive plinth with visitors at Museo della Guerra we will investigate whether this decision of balancing the automatic personalisation decisions of the system with an explicit notice to visitors on what comes next provides the necessary support for a smooth interaction.

6.4. Automatic adaptivity based on visitor behaviour models

In a scenario of tangible interaction, adaptivity gains new opportunities such as to react to the current contextual situation by changing the physical settings (e.g. triggering the vibration of an object or turning on lights), or to change objects created on demand (e.g. through 3D printing). This can be obtained with interaction rules (in Layer 3) that instruct how to shape the physical elements.

6.4.1. Exploiting the visit history to generate personalised souvenirs

We use the personal interaction history collected during the visit to generate tangible souvenirs that capture what visitors have experienced onsite. This is an advanced form of material adaptivity as the post-visit artefact represents the physical output tailored in a personal way. The effect of this type of personalisation was evaluated in “Voices from the Past in Forte Pozzacchio”.

The logs collected during the visit are used at the check-out station (located at the exit of the exhibition): a narrative strategy for adaptive storytelling composes a personalised text that reflects the order of visit, mentions the names of the voices that the visitor has heard, contains optional phrases depending on what the visitor has actually experienced, and guarantees proper syntactic and lexical cohesion of the text after the dynamic assembling. A final sentence invites visitors to connect to the museum website to find the stories and the bibliographic references of the original documents from which the narrations were extracted. A stamp with the current date completes the souvenir. Thus visitors who have experienced the installations in different ways receive different postcards.

Evaluation results showed much appreciation for the personalised postcards (Not et al., 2017). Visitors liked the familiarity of the design concept and the format of the souvenir (a postcard to be retained for personal memory or to be shown to others), the image (the theme of the exhibition), the narrative summary (that recalls the actual experience), the opportunity to find more online. We also asked participants whether they would prefer the personalised souvenir with alternative types of texts and layouts, e.g. a postcard to send. The idea of transcribing the story item that they liked most or a booklet were discarded by all 61 interviewed visitors who preferred the personalised visit summary shown in Fig. 9. So developing complex techniques, e.g. log-based reasoning, for estimating the visitors’ top interest would not be justified in this case.

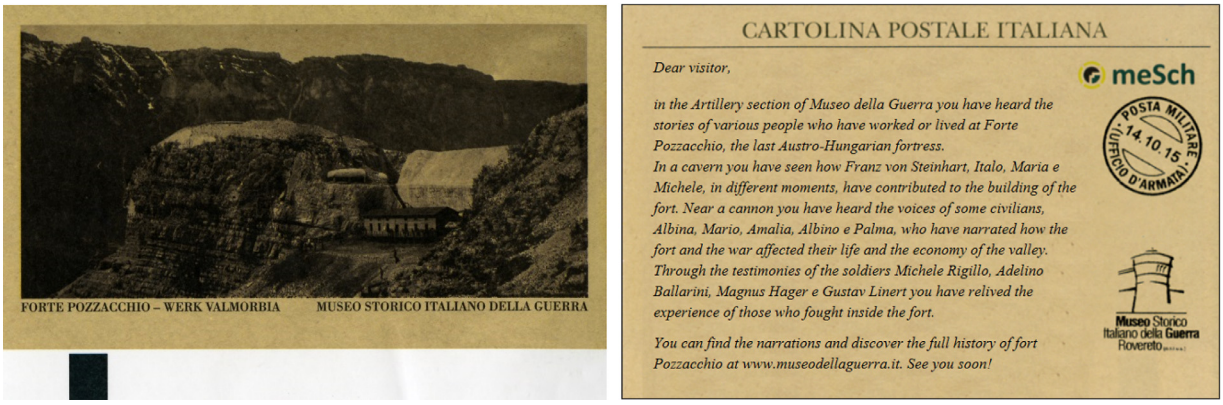

Fig. 9. Personalised visit summary generated for visitors of Museo della Guerra.

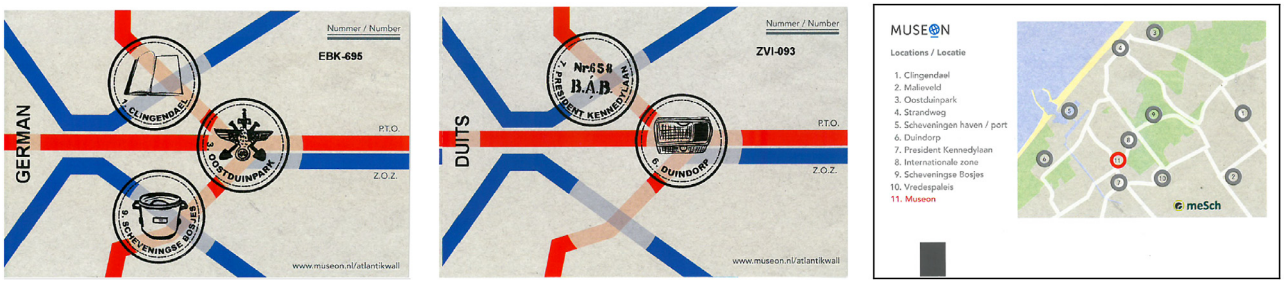

Fig. 10. The personalised souvenir summarises the highlights of the visit. The postcard on the left shows the visitor received the English narratives, followed the story of the German soldier and spent the most time at locations 1, 3, and 9. The postcard in the middle shows the language was Dutch, the perspective chosen was that of the German soldier and only two locations were visited, 6 and 7. The postcard on the right is the reverse and shows the map of The Hague with the different neighbourhood numbered as the stamps.

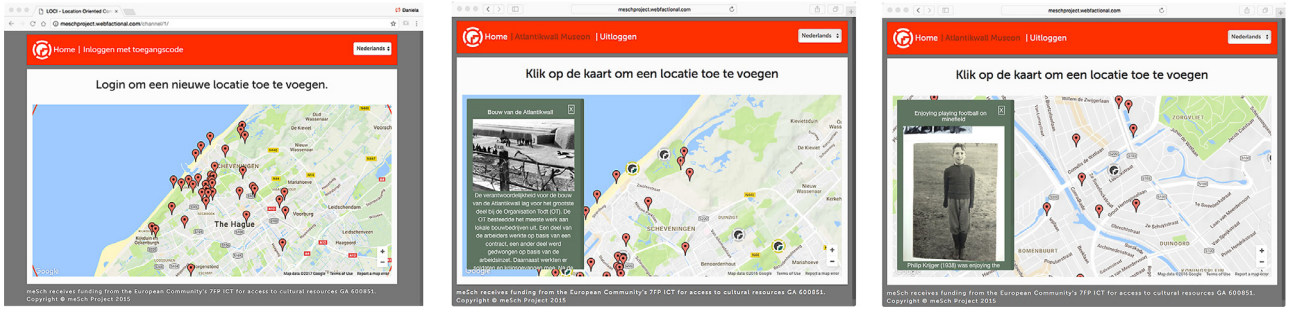

Fig. 11. The experience of the exhibition continues online: an exportable map of personal memories (left) is available to everyone while the code on the postcard gives rights to a personalised page (centre) where the content of the exhibition is overlapped onto the city and personal contribution can be added (right).

In the "Atlantic Wall" exhibition we experimented with a different layout for the souvenir, based entirely on graphics (Petrelli et al., 2017). Here the system keeps track of which stations the smart replica has been used at and for how long. As some videos were long (up to 14 min) the length of play was meaningful as many stopped it midway through and this information was used as an estimate of the interest. Each station in the exhibition was associated with a neighbourhood in The Hague and represented by a stamp: the postcard then shows the stamps of the three places where the visitors spent the longest time (Fig. 10). The postcard also shows the language and the perspective; it also gives a unique code (three letters and three numbers, top right) to be used online to enter a personalised web experience.

The reverse of the postcard shows the map of the city with the numbered spots of the neighbourhood in the exhibition that correspond to the different stamps. We wanted the postcard to be an invitation to go out and explore the city but also a way into an online system that enabled visitors to contribute their own or family memories. An interactive table-top in the exhibition allowed exploration of the visitors' contributions; the same map with pinpoints showing added content was available online, but one needed to login with a postcard code to contribute (Fig. 11). When the visitor logs in, the interaction log recorded during the visit for that code (modelled by Layer 4 of the framework) is used to generate a personalised page that shows the content of the exhibition on the city map as meSch logos. A further distinction is between the content that has been seen in the exhibition (displayed with a coloured logo) and what was not seen (displayed with a grey logo). So at a glance visitors see their visit as well as the content they missed in the exhibition and other visitors' contribution (Fig. 11).

The map-based website was developed for the Atlantic Wall as the exhibition was highly connected with the city. However we have experimented with other ways of using the logs collected onsite to personalise online experiences. In particular we have developed a generic approach that uses a tile-style layout to display the experience via different facets and enable the visitors to explore it in different ways. Fig. 12 shows the two personalised webpages automatically generated by combining content from the exhibition (prepared in Layers 1 and 2), the personal log (modelled by the system in Layer 4), and additional online material available in public repositories, such as Europeana or online databases

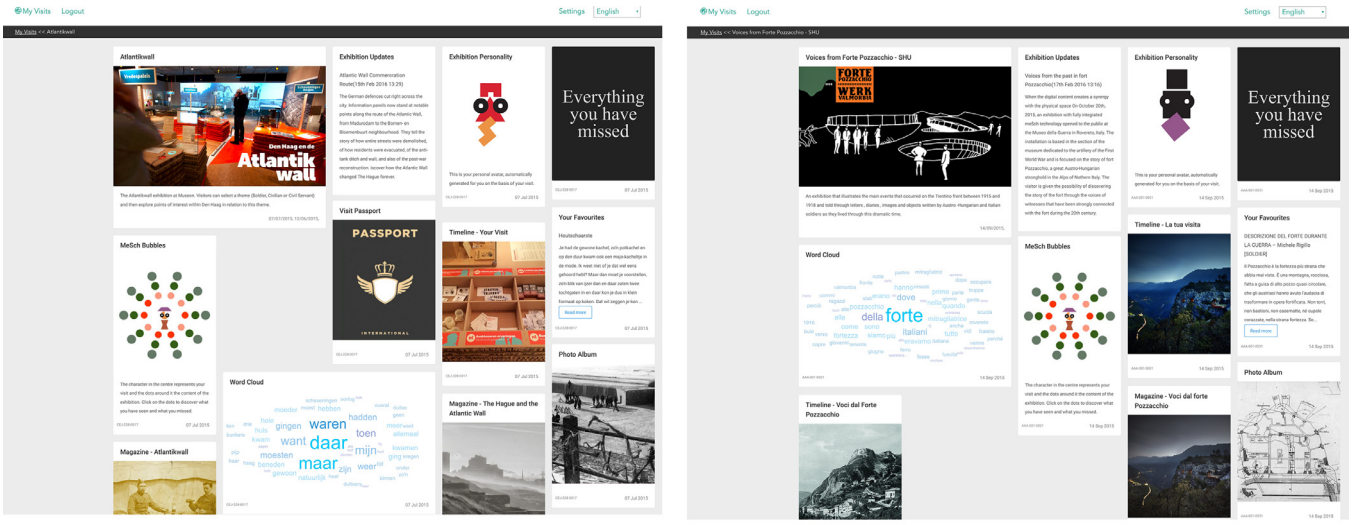

Fig. 12. The online tile-style layout of the personalised website as displayed for the Atlantic Wall exhibition (left) and the Voices from the past in fort Pozzacchio (right).

the museum wants to use to further engage visitors in an online exploration (suggested by the services in Layer 1). The two examples show many different ways to represent the visit, e.g. “everything you have missed” shows the content of the exhibition this visitor did not consume, while the “favourite” displays the single element on which the visitor spent the most time. Starting from content items of different exhibitions and from different visit traces, each visitor is shown their personalised view. A timeline shows the visit against the progress of historical facts while the exhibition personality represents in a fun way the visiting behaviour applying generic rules to the log, i.e. the dominating colour is the theme chosen, the size of the eye maps the overall engagement etc. It is worth underlining that no personal information was asked from the visitor: they just have to keep the postcard to access their entire experience online. This choice for anonymity should not be underestimated: the public is becoming more aware of the implications of giving away personal information therefore alternative ways of offering personalisation without intruding visitors’ privacy are worth exploring.

7. Discussion and conclusions

Shaping personalisation in a scenario of tangible, embedded and embodied interaction for cultural heritage involves challenges that go well beyond the implementation of content personalisation for portable mobile guides. Content is coupled with the material dimension of experiencing the objects and the spaces, thus the facets of the context are more relevant than in a situation where digital content is consumed on a mobile. The context itself combines multiple aspects, personal, social, and the state of objects and space. The endeavour of determining which features should be used to drive adaptivity has to first acknowledge what forms of personalisation curators value as most meaningful, irrespective of the complexity in modelling and implementing them. Indeed fully automatic adaptivity, where the system takes all the decisions on what to present to which visitor, when and how, may not be the best solution. Through an inspiring co-design process involving curators and museum experts, we discovered the meaning personalisation has for museum professionals and identified aspects of personalisation that curators explicitly wish to be in control of and that have been overlooked by a technology-centred perspective. Features such as “mood/emotion”, “unexpected” and “me” challenge the traditional thinking of personalisation as that of an intelligent system taking decisions on behalf of the visitor in favour of a more open approach that intertwines system intelligence with visitor’s choice and curated content prepared for specific aims. This requires a radical rethinking of how personalisation in cultural heritage manifests itself and the role curators and visitors play. The personalisation framework we developed works at different levels; it decouples content and context allowing the curators to compose different media into multiple stories delivered to the visitors in a specific context. The visitors, in turn, are not just receivers of information; they are called upon to make choices and contribute to the shaping of their personalised experience. Interaction design can become a powerful means to get the visitor into the personalisation loop: purposefully designed interactions can grant to visitor control of the adaptation of the experience, bootstrapping multiple personalisation features at the same time and relieving the system from complex log-based guessing.

Personalisation is no more solely a matter of adjusting the type and the amount of content. A synergy can be created with tangible and embodied interactions to increase visitors’ awareness they are building their own visit path, to deeply involve them through multiple senses and at the emotional level, to foster the sharing of the experience with visit companions. The accurate preparation of content that uses different strategies to connect with the place and to convey the stories in an engaging way is pivotal. The proposed framework then allows us to flexibly reuse the same content with alternative interaction experiences (e.g. in guided visits, self-directed explorations, group games), with alternative types of devices (e.g. smart activating replicas, hotspots reacting to proximity, postcards and online), and for different purposes (e.g. informing, rising surprise, fostering reflection, stimulating social interaction and discussion, favouring fun, creating a link to post-visit activities). The system takes on the burden of monitoring the state of the context, updating the information models, and applying automatic adaptivity whenever multiple options apply. By decoupling the low-level management of the context from the higher level task of structuring the narratives, we support a more sustainable porting to different hardware configurations and a reduction of complexity: by means of a bespoke authoring interface cultural heritage professionals focus on the preparation of the content according to the narrative dimensions planned for the experience, ignoring all the details related to technology. For curators, the rules for putting content in context are transparent, although they can be edited by experienced interaction designers (Risseeuw et al., 2016).

Personalisation services can also help building a long-lasting relationship with visitors by favouring new opportunities for the visitor to get in touch with the heritage (e.g. a second visit to the same place; the visit to a partner site; a follow-up online exploration). The proposed multilayer personalisation framework supports the transition between different heritage touch points, by exploiting the logs of visitors at one touch point to bootstrap the experience at the following touch point, using the information on what has already been experienced to suggest what to experience next or other interesting paths for content discovery. We explored in particular how the generation of personalised post-visit

souvenirs with their own materiality can reinforce visitors' positive attitude towards the experience, support memory and sharing, foster further curiosity and exploration of online personalised resources.

Curators are keen to invest effort on providing different visitors with the right information at the right time and with the most effective type of interaction. meSch developed a platform where personalisation technology helps curators to tailor aspects of a digitally enhanced visiting experience, the interaction modalities through which the content is disclosed, and the pace of the visit both for individuals and for groups. We believe that the direct involvement of cultural heritage professionals in the co-design of meSch technology as well as the extensive evaluation with visitors in field studies was instrumental in shaping a holistic approach to personalisation that exploits in full the new opportunities offered by the tangible and embodied interaction.

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